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This TOP describes ballistic tests to evaluate armor weldments for resistance to shock and penetration by attacking projectiles.

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Weldments, Impact velocity, Projectile velocity, I-Welds, H-Welds, Repair welds, Corner joint welds, Striking velocity

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure (TOP) 2-2-711 21 January 1994
AD No.

BALLISTIC TESTING OF ARMOR WELDMENTS

1. SCOPE. This TOP describes ballistic tests to evaluate armor weldments for resistance to shock and penetration by attacking projectiles. These tests are designed specifically for development testing.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Firing ranges	Various, to 90 m (100 yd) long, both open and enclosed
Still camera/film	To document test procedures and results
Projectiles and weapons	As indicated in test directive or specification
Protective shelters	Bombproofs, barricades, etc., to protect personnel from fragmentation and blast effects

*This TOP supersedes TOP 2-2-711, 2 November 1983.
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Item	Requirement
Temperature Chambers	To condition plates to required temperature for testing, 50°C (120°F) to -60°C (-75°F)
Radiographic equipment	For radiographing weldment
Steel butts for holding flat weldments	Capable of holding plate securely at desired obliquity
Corner joint test facility	As described in paragraph 3.5.3.2 and Figure 1

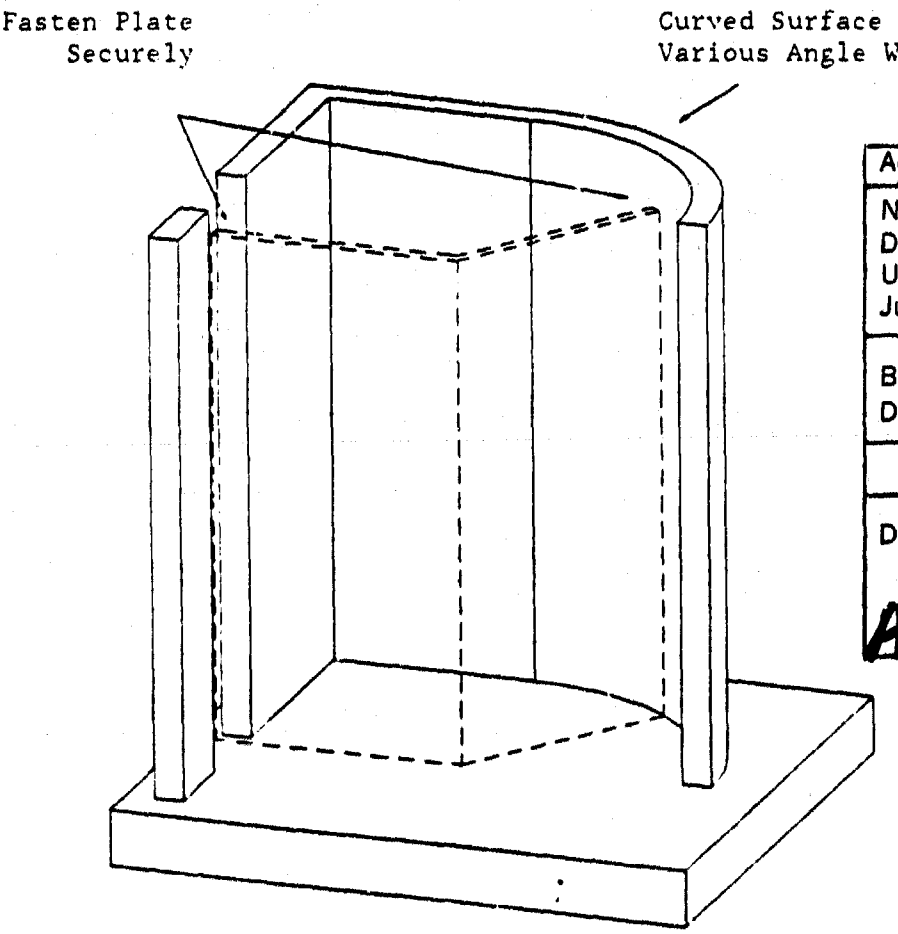


Figure 1. Corner Joint Test Facility.

2.2 Instrumentation.

Devices for Measuring	Measurement Accuracy
Velocity (ITOP 4-2-805[a**])	±0.1 percent or ±0.5 m/s
Temperature	±2°C
Plate Thickness	±0.05 mm (±0.002 in.)
Target Obliquity	±1°

3. REQUIRED TEST CONDITIONS.

3.1 Inspection. Visually inspect each test item for damage. Record a description of the test item using the applicable data collection form listed in Appendix A. The inspection data should include the following:

a. Manufacturer.

b. Plate number.

c. Dimensions (length and width).

d. Thickness.

e. Type of material.

f. Applicable military specification or standard.

3.2 Radiography. Radiograph all weldments to be tested[b]. If any area of a weldment fails to meet the radiographic standards of the applicable military specification or standard, return the weldment without testing unless authority is received to test it regardless of radiographic results.

3.3 Test Criteria. Review the appropriate military specification or standard to determine the specific test criteria and methods for assessing test results. The weldment is typically assessed by the amount of weld zone cracking.

3.4 Velocity Measurements. Use appropriate means (e.g., portable radar unit) to measure projectile velocity. Measurements taken will be the impact velocity of the projectile on the weldment.

3.5 Test Controls.

**Superscript letters/numbers correspond to those in Appendix C, References.

3.5.1 Warmer Rounds. Since a "No Test" can result if the impact does not strike at the correct velocity or location, "warmer" rounds must be fired before impacting the weldment to establish predictable velocities and impact locations.

a. Sight in gun on chipboard or other suitable material placed in target butts.

b. Fire a round with the propellant weight that is expected to give desired striking velocity. If the velocity was as expected, fire a second, confirming round with the same propellent charge. If the velocity was not as expected, vary the propellent weight accordingly and fire another round.

c. Continue until two consecutive rounds are within the required velocity and impact location tolerances.

3.5.2 Temperature Conditioning. All weldments must be temperature conditioned as required by the appropriate military specification or standard.

a. Use a surface contact probe to measure the temperature of weldments tested at ambient conditions.

b. Drill two holes in the center of two opposite plate edges and insert thermocouple probes to measure the temperature of weldments tested at low temperature. These weldments will initially be conditioned to approximately 8°C (15°F) below the prescribed test temperature using a portable temperature chamber. This tolerance allows for temperature changes during the target emplacement and weapon sighting, and may vary depending on the existing environmental conditions.

3.5.3 Plate Emplacement.

3.5.3.1 Flat Weldments. Flat weldments include I-welds, H-welds, and repair welds. These weldments shall be supported solidly on each of the two sides parallel to the longest weld(s) and normal to the line of fire, with the longest weld(s) upright. The weld to be impacted must be clearly exposed and at 0° obliquity to the line of fire.

3.5.3.2 Corner Joint Welds. These weldments must be supported in a fixture (fig. 1) designed to hold the joint with the same rigidity as in an actual vehicle. The plate to be impacted must be clearly exposed and at 0° obliquity to the line of fire.

4. TEST PROCEDURES.

4.1 I-Welds and H-Welds. The majority of I-welds are aluminum alloy, for which specific test procedures are outlined in MIL-STD-1946A[1]. The majority of H-welds are steel, for which specific test procedures are outlined in MIL-STD-1941[2].

a. Emplace the weldment in the test fixture as described in paragraph 3.5.3.1.

b. Test the weldment with the projectile, velocity, and impact location specified in the appropriate military specification or standard. Follow instructions per TOP 2-2-710[3] to fire rounds.

c. Assess the weldment based on the criteria outlined in the appropriate military specification or standard.

d. When test results from an impact are inconclusive in determining the acceptability of the weldment, a "No Test" decision will be rendered. The conditions under which a "No Test" may occur are as follows:

(1) The projectile impact is not located within prescribed limits and cracking in excess of specified limits does not occur.

(2) The projectile striking velocity is below the minimum allowed and the weld does not develop cracking in excess of specified limits.

(3) The projectile striking velocity is above the maximum allowed and the weld develops cracking in excess of specified limits.

(4) Other criteria as detailed in the appropriate military specification or standard.

e. If a "No Test" decision is rendered, impact a second round using the following criteria:

(1) For an I-weld, impact the second round on the opposite end of the weld from the first round (e.g., measured from bottom if first round was measured from top). For an H-weld, impact the second round on the opposite end of the vertical weld not previously impacted.

(2) All other test procedures remain unchanged.

(3) If any of the above "No Test" conditions occur for the second round, or if the weld develops cracking in excess of specified limits due to the second round, the entire test is considered a "No Test" and the weldment is scrapped. No more than two impacts shall be placed on these types of weldments.

4.2 Repair Welds. The majority of repair welds are cast steel, for which specific test procedures are outlined in MIL-A-11356F[4].

a. Emplace the weldment in the test fixture as described in paragraph 3.5.3.1.

b. Test the weldment with the projectile, velocity, and impact location

specified in the appropriate military specification or standard. Follow instructions per TOP 2-2-710 to fire rounds.

c. Assess the weldment based on the criteria outlined in the appropriate military specification or standard.

d. When test results from an impact are inconclusive in determining the acceptability of the weldment, a "No Test" decision will be rendered. The conditions under which a "No Test" may occur are as follows:

(1) The projectile impact is not located within prescribed limits and no spalling, perforation, or cracking in excess of specified limits occurs.

(2) The projectile striking velocity is below the minimum allowed and no spalling, perforation, or cracking in excess of specified limits occurs.

(3) The projectile striking velocity is above the maximum allowed and spalling, perforation, or cracking in excess of specified limits occurs.

(4) Cracking of the plate material outside the weld-repair area and not propagating from the weld-repair area.

(5) Other criteria as detailed in the appropriate military specification or standard.

e. If a "No Test" decision is rendered under condition (1) or (2) and enough area remains for a fair impact, impact a second round using the same criteria. If any of the above "No Test" conditions occur for the second round, or if the weld develops cracking in excess of specified limits due to the second round, the entire test is considered a "No Test" and the weldment is scrapped. No more than two impacts shall be placed on this type of weldment.

4.3 Corner Joint Welds. The majority of corner joint welds are aluminum alloy, for which specific test procedures are outlined in MIL-STD-1946A.

a. Emplace the weldment in the test fixture as described in paragraph 3.5.3.2.

b. Test the weldment with the projectile, velocity, and impact location specified in the appropriate military specification or standard. Two rounds will be impacted on this type of weldment. Follow instructions per TOP 2-2-710 to fire rounds.

c. Assess the weldment based on the criteria outlined in the appropriate military specification or standard.

d. When test results from an impact are inconclusive in determining the acceptability of the weldment, a "No Test" decision will be rendered. The conditions under which a "No Test" may occur are as follows:

(1) The projectile impact is not located within prescribed limits.

(2) The projectile striking velocity is below the minimum allowed and the weld does not develop cracking in excess of specified limits.

(3) The projectile striking velocity is above the maximum allowed and the weld develops cracking in excess of specified limits.

(4) Other criteria as detailed in the appropriate military specification or standard.

e. If a "No Test" decision is rendered for one impact, impact a third round using the following criteria:

(1) The third round will be impacted midway between the first two rounds and on the plate which sustained the "No Test" impact.

(2) All other test procedures remain unchanged.

(3) If any of the above "No Test" conditions occur for the third round, or if the weld develops cracking in excess of specified limits due to the third round, the entire test is considered a "No Test" and the weldment is scrapped. No more than three impacts shall be placed on this type of weldment.

f. If "No Test" decisions are rendered for both impacts, the weldment is scrapped and a new weldment must be submitted for testing.

5. DATA REQUIRED.

5.1 I-Welds and H-Welds. For I-welds and H-welds, use the forms presented in Appendix A, Figures A-1 and A-2, respectively, to record the following data.

a. Date of test.

b. Manufacturer, address, and point of contact.

c. Appropriate military specification or standard.

d. Type, thickness, and dimensions (length and width) of base plates.

e. Plate number.

f. Projectile.

g. Striking velocity.

h. Location of impact(s).

i. Descriptions of cracks, including sketches and dimensions (as described in app B).

j. Supporting photographs. (An example photograph of a tested H-weld plate is shown in fig. 2.)

k. Radiographic results.

5.2 Repair Welds. The data required are the same as described in paragraph 5.1.

5.3 Corner Joint Welds. The data required are the same as described in paragraph 5.1. Use the form presented in Appendix A, Figure A-3, to record the data. An example photograph of a tested corner joint weld is shown in Figure 3.

Figure 2. View of steel armor "H" plate after being subjected to shock test with proof projectile.

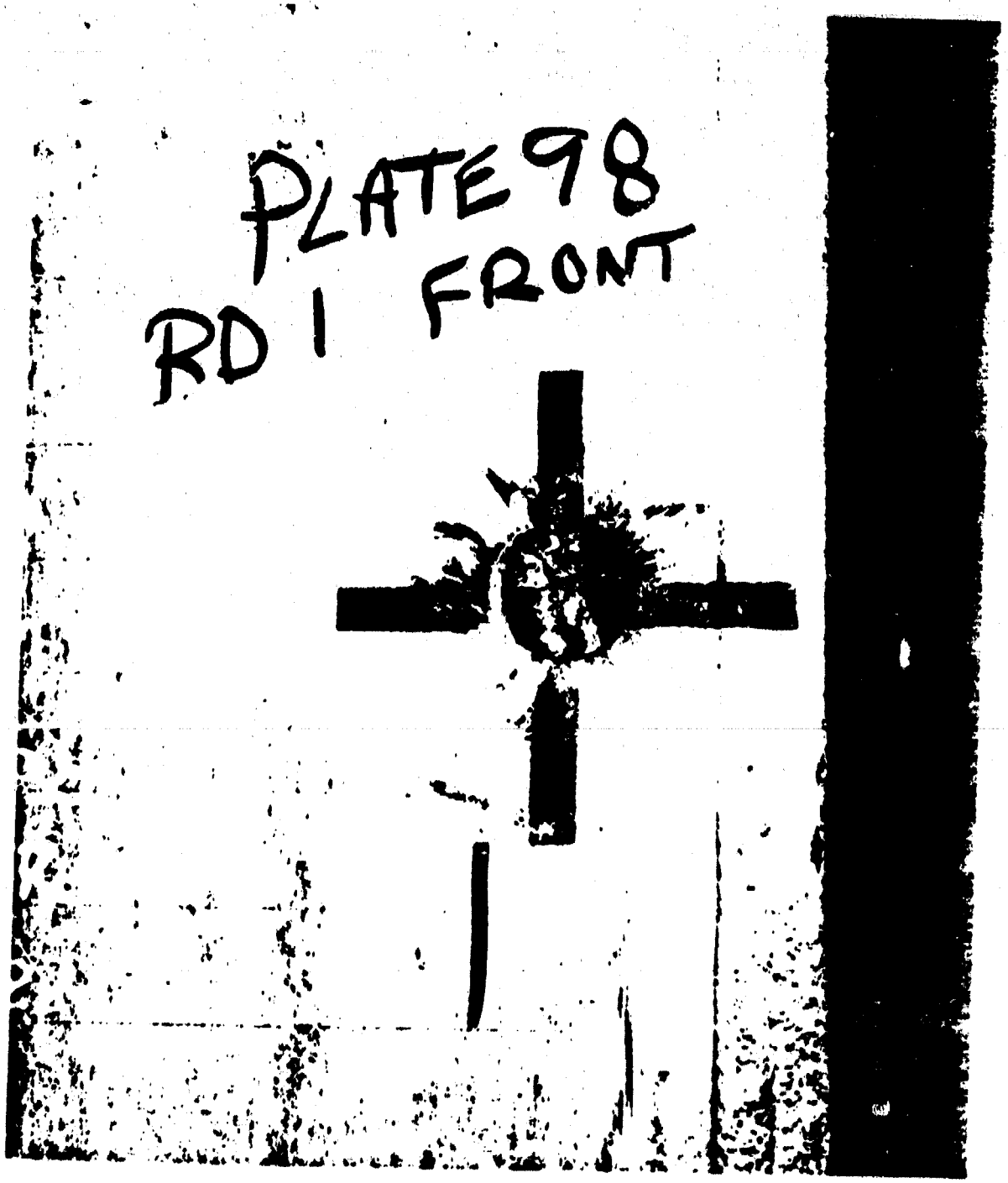


Figure 3. Aluminum corner showing location of projectile impact.

6. PRESENTATION OF DATA.

Present data in the form of a firing record as presented in Appendix A, Figure A-4.

APPENDIX A. DATA COLLECTION SHEETS AND FIRING RECORD

DATA COLLECTION SHEET FOR SHOCK TEST OF I-WELD

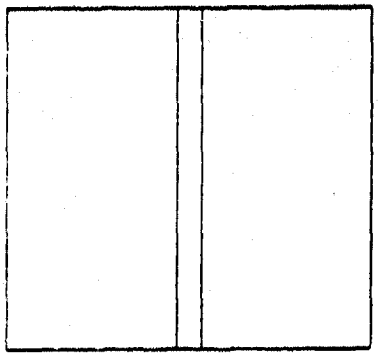
DATE OF TEST :

MANUFACTURER :
POC :
ADDRESS :

PLATE NO. :
THICKNESS :
DIMENSIONS :
BASE MATERIAL :
MIL SPEC :
PROJECTILE :

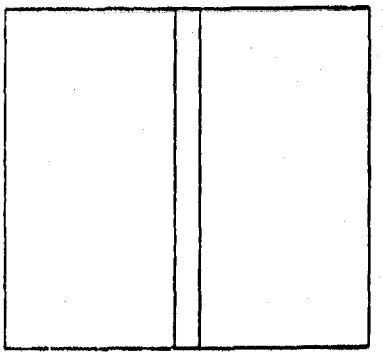
Striking Vel : _____ fps

Impact Location
From edge of plate:
From centerline of weld:



	Crack Length	
Crack Location	Front	Back
Weld		
FZ		
HAZ		
Total Weld Zone		
Plate		

BACK



* Crack Locations:
Weld (W)
Fusion Zone (FZ)
Heat Affected Zone (HAZ)
Plate (P)

Impact +

Figure A-1. Sample Data Collection Form for I-weld.

DATA COLLECTION SHEET FOR SHOCK TEST OF H-WELD

DATE OF TEST :

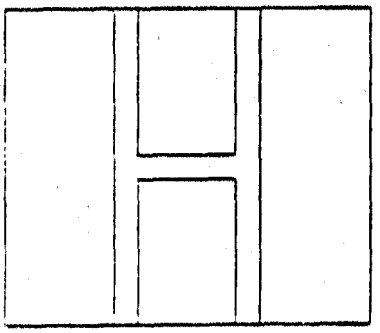
MANUFACTURER :
POC :
ADDRESS :

PLATE NO. :
THICKNESS :
DIMENSIONS :
BASE MATERIAL :
MIL SPEC :
PROJECTILE :

Striking Vel : _____ fps

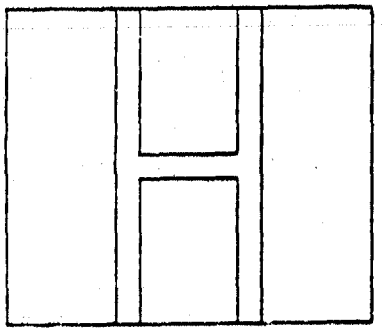
Impact Location
From edge of plate:
From centerline of weld:

FRONT



	Crack Length	
Crack Location	Front	Back
Weld		
FZ		
HAZ		
Total Weld Zone		
Plate		

BACK



* Crack Locations:
Weld (W)
Fusion Zone (FZ)
Heat Affected Zone (HAZ)
Plate (P)

Impact +

Figure A-2. Sample Data Collection Form for H-weld.

DATA COLLECTION SHEET FOR SHOCK TEST OF CORNER JOINT WELD

DATE OF TEST :

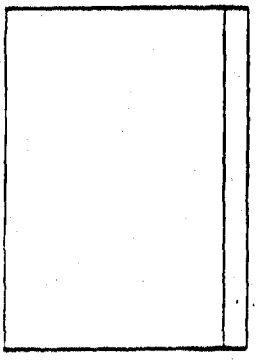
MANUFACTURER :
POC :
ADDRESS :

PLATE NO. :
THICKNESS :
DIMENSIONS :
BASE MATERIAL :
MIL SPEC :
PROJECTILE :

FIRST IMPACT

Striking Vel : _____ fps

Impact Location
From edge of plate:
From centerline of weld:

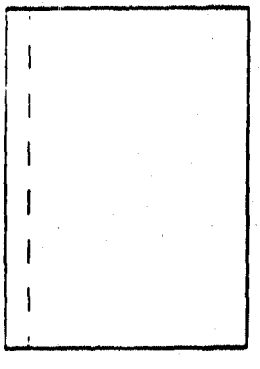


	Crack Length	
Crack Location	Front	Back
Weld		
FZ		
HAZ		
Total Weld Zone		
Plate		

SECOND IMPACT

Striking Vel : _____ fps

Impact Location
From edge of plate:
From centerline of weld:



	Crack Length	
Crack Location	Front	Back
Weld		
FZ		
HAZ		
Total Weld Zone		
Plate		

* Crack Locations:
Weld (W)
Fusion Zone (FZ)
Heat Affected Zone (HAZ)
Plate (P)

Impact ↓

Figure A-3. Sample Data Collection Form for Corner Joint Weld.

Date: 1 January 1999

Manufacturer : Weld Manufacturer
Address : 111 North Street
City, State 55555

POC : Jane Doe

A ballistic weld test was conducted on the following material by the Test Organization. The results are as follows:

Firing Record No. : 555555
Sample No. : 55

Contract No. : DAAE99999999 O.T. : 1.00"

TECOM Project No. : 1EG965000444 (If applicable)

Shot No.	Type of Material	Projectile	Req Vel (fps)	Act Vel (fps)	Total Weld Cracking (in)	Pass Fail
1	Aluminum	75-mm M1002	5555	5555	8"	Pass

Sample no. 55 passed the ballistic requirements for MIL-A-22222. The sample sustained a 3" weld cracking on the impact side and a 5" weld crack on the opposite side. The sample passed the radiographic requirements of MIL-A-22222.

If you have any questions concerning the test results, please contact Mr. John Doe, (555) 555-5555.

John Doe
Test Organization

Figure A-4. Firing Record Report For Weld Tests.

APPENDIX B. CHARACTERISTICS OF ARMAMENT WELDS

1. Evaluation of Ballistic Attack. The proper assessment of the effects of ballistic attack upon weldments can be made only after the test director has acquired a basic knowledge of the characteristics of welds and a familiarization with welding terms. The outstanding features of one type of welded joint are shown in Figure B-1.

Some terms peculiar to welding are defined below; others are defined in most welding handbooks. The welding terms and definitions used should agree with those shown in Q-STD-324[c].

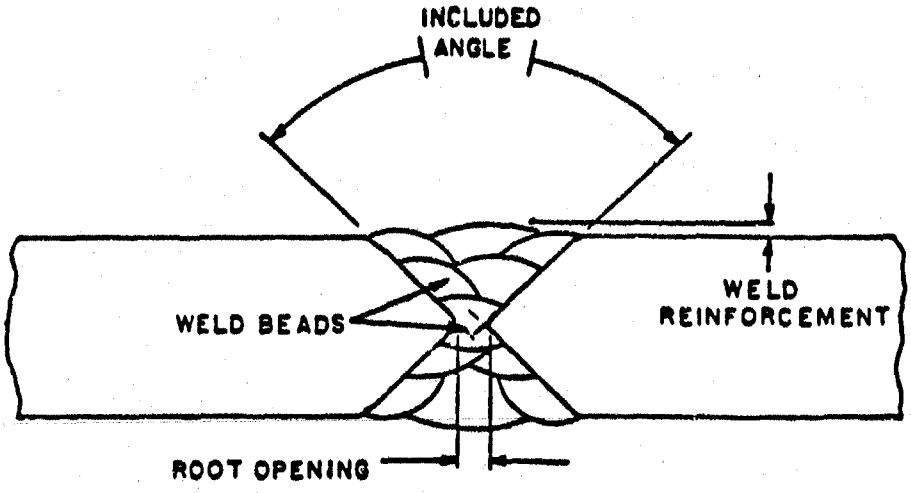


Figure B-1. Salient features of a double-V, full penetration, groove weld.

2. Types of Cracking. In ballistic tests of weldments, not only must the length of the developed cracks be reported, but also the areas in which the cracking occurred must be described. Cracking in weldments resulting from ballistic shock is divided into two general types: weld zone cracking and plate cracking. Weld zone cracking is subdivided into weld metal, fusion zone, and heat-affected zone (fig. B-2).

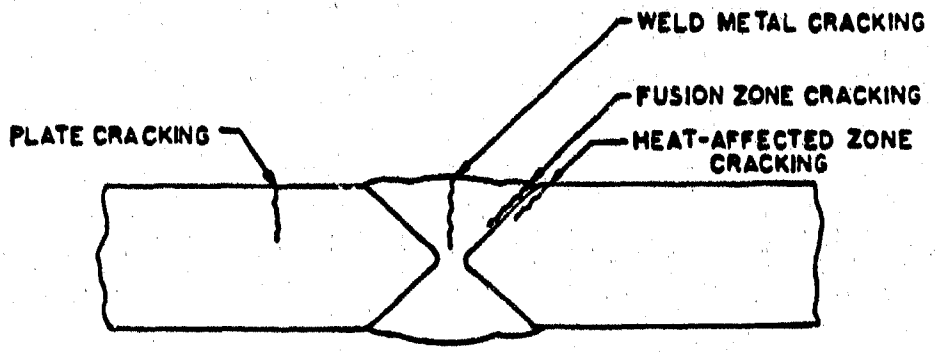


Figure B-2. Types of cracking in welded joints.

For the purpose of reporting ballistic tests, the various areas of a weldment are:

a. Weld zone - That portion of a welded joint which contains the unalloyed metal deposited by the electrode.

b. Fusion zone - That portion of the welded joint between the weld metal and unmelted base metal where the weld metal and the base metal have fused.

c. Heat-affected zone - That portion of the base metal which has not been melted, but whose microstructure or mechanical properties have been altered by the heat of welding. (For convenience and consistency, welding specifications specify cracking in the heat-affected zone to be "cracking in the armor parallel to the weld and within 0.3 cm (1/8 in.) of the edge of the weld." This "0.3-cm" rule is usually acceptable for development tests. High heat input, however, often results in a heat-affected zone that extends beyond 0.3 cm from the weld and may extend 1.6 cm (5/8 in.) in steel or even more in aluminum.)

d. Plate (or base metal) - That portion of the base metal which has not been affected by the heat of welding. (Except as noted above, any cracking that develops farther than 0.3 cm from the weld is usually considered as plate cracking.)

3. Identification of Cracking. It is not always easy to appraise and describe the cracking developed in a weldment as a result of ballistic shock. Following are three problems that frequently arise and their solutions:

a. Problem I - To determine exactly in which zone cracking has developed.

Solution I - The test director should examine the crack carefully. With the aid of the definitions in paragraph 2 and Figure B-2, a reasonable appraisal of the location of the cracking can be made. Positive identification of a crack can often be made only by microscopic examination; such examinations are usually made by the manufacturer when the plates are returned.

b. Problem II - When the cracking passes completely through the weld (from front to back), the crack usually originates in one zone at the back of the plate and may revert to another zone. The question then arises as to whether the type of cracking reported should be that which is visible on the surface of the weldment or that which exists inside the joint.

Solution II - If the crack has not opened sufficiently to permit examination of the interior, the zone in which the cracking appears on the surface is reported as the zone of cracking. When it is possible to see into the crack (usually when the weldment breaks into two or more pieces), the cracking is described in terms of that type of cracking which dominates through half of the depth of the weld from the side that is being reported.

c. Problem III - A barely discernible, silvery gray line often develops on the edge of, or within, a weld as a result of an impact. This line usually runs along the junction of the weld reinforcement and the base metal but may occasionally be in the weld metal itself. It is often difficult to determine whether all or part of this line is an incipient crack.

Solution III - Sometimes a silvery gray line forms as a result of the displacement of cracking of scale, rust, or flux. When such a line develops and close examination reveals no trace of a fissure, it is not considered as cracking. Any cleavage of definite break in the metal, however, should be considered as cracking. Even so, it is often difficult to determine whether cracking actually exists and, when it does exist, where it terminates. When a definite answer is required, magnetic particle or dye penetrant examination should be used (TOP 3-2-807[d]).

APPENDIX C. REFERENCES

REQUIRED REFERENCES

1. MIL-STD-1946A(MR), Welding of Aluminum Alloy Armor, 7 June 1989.

2. MIL-STD-1941(MR), Metal-Arc Welding of Homogeneous Armor, 23 September 1983.

3. US TOP 2-2-710, Ballistic Tests of Armor Materials, 7 February 1984.

4. MIL-A-11356F(MR), Armor, Steel, Cast, Homogeneous, Combat-Vehicle Type, 1/4 to 8 Inches, Inclusive), 22 May 1987.

REFERENCES FOR INFORMATION ONLY

a. FR/GE/UK/US ITOP 4-2-805, Projectile Velocity and Time of Flight Measurements, 29 November 1991.

b. MIL-R-1264, Radiographic Inspection: Soundness Requirements for Arc and Gas Welds in Steel, 16 August 1982.

c. Q-STD-324, Welding Terms and Definitions.

d. US TOP 3-2-807, Nondestructive Testing of Materials, 5 December 1985.

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